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SUBJECT: Review of HS reports developed by the Worker Health and Safety Branch from field studies where monitoring involved treatments using reduced-volume spray equipment.

This is a review of Worker Health and Safety (WH&S) reports where sampling was conducted after pesticide applications to compare conventional application equipment and reduced-volume application technology. The reference number is used to identify each study.

Dislodgeable Foliar Residue Studies (DFR)

<u>DFR studies on orchards or field crops</u>

Walnut orchards [1] were sampled to compare DFR levels after electrostatic and conventional applications. They reported results 2 to 4 fold higher for the electrostatic applications when phosalone was applied at the same rate of active ingredient (AI). The two types of applications had similar decay rates and the 2 to 4 fold differences in DFR levels held up over the 21-day sampling period. DFR levels were measured after conventional and reduced-volume, charged-spray applications using captan on strawberries [2,3]. Treatments for the electrostatic applications were a charged spray at full rate AI, uncharged spray at full rate AI, and a charged spray at half rate AI. The conventional application was applied at full rate AI. Only the charged spray at full rate AI showed a 1.2 (7.03 vs. 5.33 $\mu g/cm^2$) times higher initial deposition when compared to the conventional application [2]. Sampling was also conducted to measure differences in exterior and interior leaves of the plant and upper and lower leaf surfaces [3]. Exterior leaf DFR levels were twice the interior leaf levels for both application types. For the conventional application there was no difference in upper and lower leaf surfaces while the electrostatic application showed a two-fold increase on the upper leaf surface. Knowing that distribution patterns of the pesticide can vary within the plant canopy is useful when sampling foliage contacted by the worker during harvest. DFR levels were measured on lima beans after application of dicofol and dimethoate [4]. The initial deposition for the reduced-volume application was approximately half the conventional application when applied at full rate AI for both pesticides. In addition, initial deposition for a half rate electrostatic treatment was about one third full rate conventional treatment for dicofol and dimethoate. Decay rates were similar across application methods and AI rates for each compound.

Greenhouse Studies

One greenhouse study [5] reported contrasting a reduced-volume electrostatic hand wand application to an application using the more conventional wet spray hand wand. The pesticide was applied at the same rate of AI. The reduced-volume application had a four-fold increase in initial deposition levels over the conventional wet spray method using the standard extraction method of multiple surfactant washes. Using a mechanical method of removing and collecting solids off the leaf surface found no significant difference between the two application technologies. When reduced-volume treatment rates were half or less the AI rate of the conventional application, only one study [6] reported reduced-volume initial deposition equal to the conventional spray application. Two other studies [7,8] reported lower DFR levels from reduced-volume applications when applied at half the AI rate of the conventional application.

Air Monitoring Studies

For two studies [9,10] air concentrations were measured after fogging applications. Air concentrations of the pesticide increased during and after the fogging applications, but fell below the detection limit during ventilation. The studies show that delaying entry to allow for ventilation of the greenhouse would mitigate any inhalation hazard for reentry workers. The foliar residues were less than those of the more conventional full coverage spray and would not pose additional hazards to reentry workers.

Worker Exposure Monitoring Studies

Only one study [11] monitored workers applying pesticides to almond trees using reduced-volume technology and the more conventional full coverage spray. The two reduced-volume applications monitored showed similar exposure results in mg per pound applied. The applicator using the more conventional dilute application had a potential exposure four times that of the reduced volume application. This difference may be due to droplet size for the reduced-volume spray has somewhat smaller and uniform droplets that take a fractionally longer time to settle out leaving the applicator ahead of the fallout. In the conventional application, the larger droplets in the spray spectrum settle out almost as fast as they come out of the nozzle causing the greater exposure potential.

Using an electrostatic hand wand doubled potential inhalation exposure compared to a conventional hand wand application in greenhouses [5]. Breathing zone concentrations were measured; if we assume a protection factor of ten for a half-face respirator [12] levels would be below 0.01mg/m^3. This same study conducted dosimetry sampling on the applicator and harvester using whole body clothing and handwipe/handwash technique. Two positives were reported at just above the detection limit from long underwear bottoms worn by the applicator and harvester exposed to the reduced-volume treatment. Potential exposure estimates calculated from these samples would not be considered hazardous.

Conclusions

It would appear from these studies that applicators are at no greater risk during reduced-volume applications. The amount of pesticide being applied at any given time is no different then that of a conventional full coverage spray. While increases in potential inhalation exposure inside a greenhouses could occur without a respirator the current practice is to wear a respirator during pesticide applications. DFR residues are ambiguous with some studies showing a potential for increased initial deposition and thus field worker exposure. From a reentry standpoint, if the initial foliar residues were higher a worker entering 12 hours, 2-days or a week later would be exposed to potentially higher residues. This assumes that all foliar residues are equally available regardless of how the material is applied. Two studies [3,5] reported mechanically removing foliar residues with a mite-brushing machine that removes and collects solids from the leaf surface. Under this method of residue removal, that is likely to be similar to field worker exposure, DFR's were 12-14% for the reduced-volume applications and 14 to 30% for the conventional applications, of the standard extraction technique using multiple surfactant washes. WH&S studies have shown similar worker exposure levels for workers exposed to similar DFR levels of a pesticide [13]. Thus, there is little point to conducting worker exposure monitoring unless DFR levels resulting from electrostatic applications differ significantly from levels resulting from conventional applications. WH&S studies indicate that electrostatic applications do not routinely result in higher DFR levels compared to conventional applications. In addition, under commercial use they usually cut back the rate of application when using reduced-volume equipment. Researchers [13,14,15] have also reported finding residue levels twice that of the previous years although application rates and equipment (conventional air blast sprayers) were unchanged along with similar weather conditions.

Study summaries

HS-1394 [1] reports on a DFR study of three electrostatic treatments and three dilute treatments to walnut orchards. All six treatments were applied at 2.25 pounds AI per acre of phosalone. Electrostatic treatments were applied in 25 gallons of water and the dilute treatments were applied in 165 gallons of water. Leaf disks were collected pre application, one and twelve-hour post application and 1, 2, 3, 7, 14 and 21 days after. Decay rates were similar for both application types but the electrostatic application had higher DFR levels throughout the monitoring period. Initial deposition for the electrostatic application was significantly higher at $p<0.01$. With some electrostatic values four times the dilute application. While the electrostatic levels were higher they were comparable to previous studies by this department. The investigators did not consider the residue levels hazardous to workers. Outliers in the data set for the electrostatic application presented difficulties in comparing it with the dilute applications.

HS-1660 [2] reported on the investigation of DFR levels of captan applied to strawberries using an electrostatic charged full-rate application, an uncharged full-rate application, a half-rate charged application and the conventional application. Three of the applications used the same AI per acre of two pounds while the half rate charged used a one pound AI rate per acre. The conventional application used 200 gallons of water per acre while the three electrostatic applications were applied at 8.5 gallons per acre. DFR samples were collected at two hours and 1, 3, 4, 7 and 14 days. The full-rate charged treatment showed an increase in initial deposition of 1.2 times the conventional application with a longer decay rate. The decay rates were similar for the other three treatments. Assuming workers would enter the fields every three days to harvest strawberries and a 14-day reapplication interval the authors used transfer factors to calculate cumulative potential exposure. For ungloved workers, working in fields treated using the electrostatic technology at full rate, a 75% increase was calculated. When they estimated exposure for gloved workers, the electrostatic treatment would have been 69 mg. This is about 14% of the exposure estimated for ungloved workers from the conventional application.

HS-1663 [3] is an adjunct to HS-1660 [2]. Differences in deposition of captan on strawberry foliage were measured by sampling leaves considered exterior to the plant canopy (those in plain view) to leaf samples considered interior to the plant canopy (hidden from view). The investigators also sampled whole leaves and used the leaflets to sample residues from the top and bottom of different leaflets with a mite-brushing machine. Used by entomologists to quantify infestation, it removes and collects solids from the leaf surface. The methods of application and the rates were the same as those stated for [2]. Mean residues from the exterior of the plant canopy were significantly higher (480 – 740 µg/g) then interior surfaces (260 µg/g to 410 µg/g). The mechanical removal of residues from upper and lower leaflet surfaces found no differences in residues using the conventional application technology. The electrostatic application did result in a significant difference in upper and lower leaf surface residues ($p=0.001$). Residues were 1.8 times higher on the upper surface of the leaflet using the leaf brushing method. The study showed that pesticide residue is not evenly distributed within the crop canopy and consideration should be given to sampling those areas of the foliage contacted by the worker during harvest.

HS-1793 [4] reported on comparing a full coverage spray application to a full rate and half rate electrostatic application to lima beans. Two pesticides, dicofol and dimethoate were used in each treatment. Both the conventional and full rate electrostatic treatments applied 0.5 pounds AI of dimethoate and 1.5 pounds AI of dicofol per acre. The half rate treatment was 0.25 and 0.75 pounds AI for dimethoate and dicofol, respectively. The dilution was 26 gallons of water for the full coverage spray and four gallons of water for the two electrostatic treatments. DFR samples were collected pre application, 8 hours post-application, 1, 2, 3, 7, 14, and 21 days post-application. Off target sampling was conducted using fallout cards following application. For both pesticides, the respective decay rate was consistent among all three treatments. Dimethoate exhibited a constant dissipation rate while dicofol dissipation was multi-phasic. Off target deposition for dicofol was significantly greater then foliar deposition for all treatments. Dimethoate deposition off target was only marginally higher than initial foliar deposition. Initial foliar deposition for both pesticides was significantly greater for the conventional application then the electrostatic full rate treatments, that was in turn greater than the half rate electrostatic application.

HS-1643 [5] reported on a study conducted to contrast a reduced-volume electrostatic hand wand application to an application using the more conventional wet spray hand wand. Permethrin was applied to chrysanthemums at 1.3 pounds AI per acre. The tank mixture for the conventional wet spray application was 245 gallons per acre and for the electrostatic treatment five-gallons per acre. Applications were made in both summer and winter. DFR samples were taken pre application and at 1, 3, 7 and 14 days post application. Nontarget deposition was also measured using filter papers on bench top and aisleway surfaces. Whole leaves were sampled on day one and used in a leaf brushing technique to estimate DFR. The reduced-volume application resulted in an almost four-fold increase in foliar deposition at 1.29 $\mu g/cm^2$ compared to 0.35 $\mu g/cm^2$for the conventional application. The decay rate for the winter electrostatic application was significantly longer then the decay rate for the electrostatic application completed in the summer time or the summer and winter conventional applications. There were no significant differences between any of the other decay rates. Nontarget deposition was greater for the conventional application because of the larger droplet size and higher spray velocity causing material to pass through the plant canopy. The leaf brushing procedure used a mite-brushing machine, commonly use by entomologists to quantify infestation, to remove and collect solids from the leaf surface. This technique found no significant difference between the two application technologies. This suggests that the higher DFR levels found following electrostatic applications may not effect a change increasing potential worker exposure. The application technique may have changed the mechanical transfer of leaf residue.

A study conducted on greenhouse grown roses [6] was similar to one conducted earlier on chrysanthemums [5]. Two types of equipment were used. A more conventional treatment applies pesticide using a five-nozzle spray hand wand and the other was an electrostatic handgun sprayer. Application rates were 0.8 pounds AI in 179 gallons of water for the conventional treatment and 0.4 pounds AI in 3.6 gallons of water for the electrostatic treatment. The rates were considered typical of commercial practice at the time. Dual DFR samples were collected from the upper and lower regions of the plants at >1 m and <1 m, respectively. Whole leaves were also collected from the upper regions of the plant for use in the leaf brushing technique. Potential worker exposure was monitored during application and at harvest 24 hours later using clothing dosimetry, hand wipes followed by hand wash and personal air pumps for inhalation exposure. DFR deposition was equivalent for the two methods with no statistical difference found. The lower canopy deposition was a third to a fourth less than the upper canopy and was expected because the applicator targeted the upper canopy. Immediately following application air levels were higher for the electrostatic application but a one-hour sample that began 45 minutes after application found no permethrin above the detection limit of 0.15 $\mu g/cm^2$ for either treatment. Dermal sampling for the hands and torso were below the detection limit in all instances. Positive dermal results were found on workers wearing long underwear bottoms during the electrostatic application at 0.18 mg/25 minutes and the harvester at 0.16 mg/hr. These measurements of potential dermal exposure were just above the detection limit. Inhalation levels for the applicators were 0.19 mg/m^3 and 0.008 mg/m^3 for the electrostatic and conventional treatments, respectively. Respiratory protection for the applicator and adherence to reentry intervals could mitigate any differences in inhalation results.

DFR levels of bifenthrin were monitored for three types of reduced-volume application equipment and a full coverage spray treatment (HS-1755 [7]). Use rates were those suggested by the manufacture and typical of commercial use. The equipment was all hand held and included a coldfogger, air-assisted electrostatic handgun, pulsefogger and a conventional hydraulic sprayer with hand wand. The bifenthrin rates per cm^2 of bench area were 812 µg coldfogger, 1015 µg electrostatic handgun, 2030 µg full coverage spray, and 115 µg pulsefogger. The theoretical initial deposition for the coldfogger and electrostatic handgun were a third to a half of the full coverage spray. The pulse fogger, applied at about one-twentieth rate, resulted in a deposition half the full coverage spray. None of the reduced-volume applications exceeded the DFR levels found in the full coverage spray.

In study HS-1780 [8] investigators collected DFR samples following a full coverage spray application and an electrostatic application of abamectin to gerbera plants grown in greenhouses for flower production. Rates were 0.0058 pounds AI in 2.5 gallons of water for the electrostatic treatment and 0.0094 pounds AI in 100 gallons of water for the conventional application. Mean deposition four hours post application was 0.002 $\mu g/cm^2$ for the electrostatic treatment and 0.035 $\mu g/cm^2$ for the full coverage spray. Half-life data was similar at 1.5 days. While both applications produced low DFR levels because of the amount of material applied, the very low levels found for the electrostatic application were attributed to 60% less material applied and poor penetration of the plant canopy.

HS-1403 [9] described monitoring of a stationary thermal-fogger application and a hand wand application in greenhouses. Air concentrations were measured at 1, 2, 13 and 16 hours post application. DFR samples were not collected. The pesticides applied per 10,000 ft^3 were chlorothalonil and permethrin at the rates of 0.39 and 0.05 pounds AI, respectively. Due to the differences in pesticide treatments and greenhouse conditions, no comparisons were made between the fogger and hand wand applications. While no direct comparisons can be made the airborne levels one to four hours after application were higher then any values found during the hand wand applications. The detected levels one-hour after application were 3.2 mg/m^3 and 0.7 mg/m^3 for chlorothalonil and permethrin, respectively. Detectable levels of pesticide could be found up to thirteen hours after the thermal fogger application but after a two-hour ventilation period no detectable residues were found.

In HS-1729 [10], researchers monitored a fogging application to an ornamental crop to evaluate droplet size and air concentrations. A forward-scatter laser spectrometer measured and categorized droplet size. Vacuum-type air samplers, measured the air concentrations. The results showed rapid settling of the aerosol. Airborne levels were below the detection limit of 1.3 $\mu g/m^3$ after the greenhouse was vented at 13 hours. Estimated potential exposure just prior to venting was calculated at 0.07 $\mu g/m^3$. This study and the study described in HS-1403 show the necessity of venting the greenhouse prior to entry to alleviate the inhalation exposure.

Investigators evaluated ground applicator exposure during two electrostatic applications and one conventional air blast treatment to almond trees (HS-1407[3]). Treatment rates were similar at 1.4 and 1.5 pounds AI azinphosmethyl per acre for the two electrostatic and one dilute application, respectively. The reduced-volume electrostatic equipment sprayed at a dilution rate of 25 gallons per acre and the conventional air blast used a dilution of 100 gallons of water per acre. Gauze pads mounted outside and under Tyvek[R] coveralls along with hand washes were used to measure worker exposure. The higher dilution rate corresponded to a potential exposure of 5.3 mg per pound applied for the ground applicator compared to 1 mg per pound for each of the two electrostatic applications. While the data is limited, it does not show an increase in exposure for applicators using reduced-volume equipment.

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